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ABSTRACT

Simulation as a mode of computer use in instruction has been neglected by educators. This paper briefly explores the circumstances in which simulations are useful and presents several examples of simulation programs currently being used in high-school biology, chemistry, physics, and social studies classes. One program, STERIL, which simulates screw-worm fly population changes with the use of pesticides and sterilization techniques, is discussed in detail. (RB)

DIGITAL SIMULATION IN EDUCATION

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DIGITAL SIMULATION IN EDUCATION

I. Introduction

Educators have found many ways of using computers. At the high-school level, computers are used primarily for administrative purposes; while at the college level, the computer is used for educational purposes as well as for administrative ones. These educational uses at the college level have been associated primarily with programming courses, or with large-scale or difficult computations (e.g., in nonlinear, or distributed systems).

One mode of computation which has been largely ignored among educators is the simulation mode. One notable exception is Huggins' JOBSHOP (1). Medical schools are beginning also to explore the uses of simulations in development of diagnostic technique (2), as well as in other ways.

Huggins (3) has characterized the digital computer as a highly-flexible laboratory in which we may explore any environment we wish. It is with this mode of computer utilization that we shall be concerned in this paper.

The author has been working for several years with high-school teachers in explorations of the utility of computer simulations in their curricula. Simulation programs have been found to be effective in biology, chemistry, earth science, physics, and the social sciences (4).

In the paragraphs below, we shall explore the circumstances under which simulations are useful, and shall present several examples of simulation programs which have been developed recently.

II. A Rationale for Simulation

Few people would dispute the desirability of learning by direct experience. The investment of billions of dollars by our universities, and by our primary and secondary schools in laboratory facilities is evidence enough. Generation after generation of students re-measure the acceleration due to gravity, or re-discover Ohm's Law, or study the giant chromosomes of the drosophila fly, even though these things have been done by very capable scientists employing the most elaborate facilities available. How much easier (and how much less expensive) it would be to describe Millikan's oil-drop experiment, and its results, along with pictures of the apparatus, in a textbook -- yet many physics laboratories in high schools and colleges are equipped with this apparatus, and, every year, legions of students repeat this experiment. Their e/m ratios are very imprecise compared to the carefully-determined value of the physicist; however, they have benefitted from having had the experience themselves. This is as true for non-scientists, who never again will have a laboratory experience, as it is for the physicist who will spend his life in the laboratory.

Even though direct experience is very desirable, our students frequently are prevented from such learning experiences. Some of the reasons for this are:

1) The necessary equipment is not available because of expense or it is too complex or delicate to permit students to use it (e.g., in high-energy physics).
2) The sample size available in the real world is too small to permit generalizations (this is especially true in the training of medical students in the diagnosis of disease.

Medical students in New York State, for example, run into very few cases of malaria, and develop little experience with it).

3) The experimental technique is difficult and must be developed over an extended period (e.g., in experiments in genetics, and in titration).

4) There are serious dangers to the student (e.g., where radiation or high temperatures are involved, where there may be explosive mixtures of gases, or where highly-toxic materials are required).

5) The time scale is too short or too long to permit the student to make observations (e.g., the runaway of a nuclear reactor -- here, of course, there are other reasons for not permitting students to do the experiment -- or the study of the dynamics of populations).

6) The opportunity to experiment directly is not available (e.g., in studies of economic, politcal, or social systems, or in studies of human genetics, or spread of disease).

7) When it is desirable to measure variables which are difficult to access (e.g., the tension on a pendulum string, or the differential effects of the gravitational effects of the earth and the moon on an orbitting satellite).

8) When measurement and other noise obscures the important phenomena (in the computer, we can create a world in which there is no noise and in which instruments are

perfect, and then show the student how these things obscure the data of interest).

9) There are times when it is useful to underscore the significance of natural laws (e.g., study of non-inverse-square-law gravitational systems (5), or non-Mendelian genetics).

If any of the foregoing circumstances exists, the student normally is excluded from learning by direct experience. Typically, here, he learns by reading a textbook, or by attending a lecture on the subject. In both cases, the learning is less than completely satisfactory. (Who would accept a surgeon who has learned surgery solely from books and lectures?)

Simulation is an educational tool which can overcome the foregoing inhibitions; and which can provide, in many cases, a far better learning situation than can be provided by either textbooks or lectures.

It should be emphasized that simulation is proposed as a complement to existing educational techniques, rather than as a substitute for any of them.

III. Examples of Educational Simulations

Several examples of simulations developed by the author and his colleagues are described below. These simulations were developed for high-school students in biology, chemistry, physics, and social studies; however, they are appropriate for college students, at least at the freshman level. They have been used successfully by such students at two colleges (the Polytechnic Institute of Brooklyn and the State University of New York at Farmingdale).

A. STERIL

One pest-control technique which has proven to be very successful in control of screw-worm flies is the "sterile-male" technique, in which male flies are raised in a laboratory, sterilized by irradiation, and, then, released in infested areas. These sterilized males compete with normal males for the females. The success of the technique depends upon the fact that females mate only once. Those which mate with sterile males lay unfertilized eggs, and fail to reproduce. This technique is described in an interesting paper by Knipling (6), and in an extensive report (7).

A simulation program called STERIL (developed by A. Frishman, C. Losik, and this author) permits the student to explore the relative merits of pesticides, sterilized males, and combinations of these two, in the control of screw-worm flies. The student is able to develop, and try out, various policies for controlling, and eliminating, these pests.

Several sample runs of this program are shown in Figs. 1-7. In Fig. 1, a pesticide is applied every seven days, but no sterile males are released. Here, there is a steady-state oscillation with a seven-day period and an average level of 0.25 million normal males. The population increases after each application of pesticide, because of immigration into the area, and because of eggs laid by earlier generations.

In Fig. 2, pesticide is applied every day for 24 days only (again, no sterile males are released). On the twenth-fifth day, the population begins to grow again, because of immigration; and, by the seventieth day, it returns to one million -- the carrying capacity of the area.

The approach shown in Fig. 3 consists of the application of pesticide only once on the first day. From then on, one-hundred-thousand sterile males are released each day. Here, the normal population declines continuously beginning on the sixth day; until, on the seventy-fifth day, it is reduced to sixty thousand.

Fig. 4 shows the result of a policy similar to that of Fig. 3, except that only ten-thousand steriles are released each day. This policy decreases the steady-state normal population only to 880,000. One interesting characteristic of this policy is the dips at days 21, 41, and 61. The twenty-day period is a result of the twenty-day period from the laying of eggs to the maturation of the new females and their laying of eggs.

The result of application of pesticide once, and release of 100,000 sterile males each day for twenty-four days is shown in Fig. 5. Again, because of immigration and maturation of already-laid eggs, the population returns to 1,000,000 sterile males. Here, the steady-state average is 0.18 million compared to 0.25 million in Fig. 1. This slight reduction, in spite of the large number of sterile males released each day, occurs because the pesticide is non-selective. Sterile and normal males are affected equally.

The policy of Fig. 7 (pesticide only for the first ten days, and then no control) shows that early termination of control causes more-rapid return to normal population levels than with extended control programs -- either pesticide or sterile males (c.f., Figs. 2 and 6).

Clearly, this program permits exploration of a circumstance which the student could not study directly, except perhaps in graduate school,

and which he could not study analytically because of the complexity of the equations.

B. KINET

The program KINET permits the student to explore the dynamics of a chemical system in which a specific compound is converted to a single daughter-compound. The student specifies the forward-rate constant, and the equilibrium constant. From these parameter values, the computer produces plots of the concentrations of mother and daughter species as functions of time.

Four sample runs of this program are shown in Figs. 8-11.

KINET was developed by J. Marchisotto and H. Shannon.

C. SLITS

One of the classic experiments in the elucidation of the wave properties of light was Young's Double-Slit Experiment. This experiment can be performed directly, even by high-school students; however, because of equipment limitations, there are severe restrictions on parameter ranges, and on the depth of exploration available to the student. SLITS is a simulation of this experiment which permits the student to explore parameter values over a wide range, to observe, in detail, the variation of light intensity along the viewing screen (this is extremely difficult to instrument in the laboratory), and to draw inferences about the inter-relationships among the variables.

Three sample runs of this program are shown in Fig. 12.

This program was developed by A. Caggiano.

D. GENE1

In the study of genetics, students usually have difficulty appreciating the probabilistic nature of the transfer of genetic traits from parents to offspring. GENE1 has as its purpose the development of an understanding of the fact that the Mendelian ratios apply only when large numbers of offspring are involved.

Sample runs of this program are shown in Figs. 13-16. In these runs, there are increasing numbers of offspring. Theoretically, for this set of genetic traits, the Mendelian ratios are: genotype ratio -- homozygous dominant: heterozygous: homozygous recessive = 1:2:1; phenotype ratio -- dominant: recessive = 3:1. (In this example, brown eye color is dominant over blue.

For 10 offspring (Fig. 13), the actual ratios are far from the theoretical ones (1:6:3 and 2.33:1; rather than 1:2:1 and 3:1). As the number of offspring increases, the ratios approach the theoretical values. When there are 10,000 offspring, the actual ratios are 1:1.93:1.03 and 2.84:1 -- within 5% of the theoretical values.

This program was developed by the author.

E. SCATTER

This program simulates the phenomenon called Rutherford, or Coulomb scattering. Here, a series of energetic particles is fired at a target particle. The output of one run of this program is shown in Fig. 17. The target nucleus is located at the T in the center of the plot. There are five equally-energetic particles released at different locations with respect to the target particle. These

five particles scatter by an amount which varies inversely with distance from the target axis.

This program was developed by A. Caggiano and D. Scarl.

F. ECON1

This program is a very simple-minded simulation of the economy of the United States. The plot of Fig. 18 shows the variations in net national income with various taxing, governmental spending, and investment policies. (This program was developed by the author.)

IV. Conclusion

Several examples of educationally-oriented simulation programs have been described. All of them have been found to be useful pedagogically; and at least two (SLITS and STERIL) have been received very enthusiastically by students.

One fact which has emerged clearly from this developmental effort is the need for a diversity of backgrounds and capabilities in the development of these simulation programs.

The discussion of STERIL above is extensive primarily to show the versatility and relatively-high fidelity of the simulation model used here. This program required the combined skills of a very capable programmer, a knowledgeable biologist, and a system engineer with experience in model building.

It is clear to this author that, before simulation begins to have the dramatic impact on education which it offers potentially, more subject-matter specialists, system engineers, and computer scientists from the universities, and from industry, must begin contributing to the development of material.

References

1. Lutz, K. J., "The Homewood Electronic Jobshop"; The Johns Hopkins University, Baltimore, Maryland, 1969.

2. Russo, J. E., "Exercise in Medical Diagnosis", Polytechnic Institute of Brooklyn, Brooklyn, New York, 1970.

3. Huggins, W. H., private communication.

4. Huntington Computer Project Teacher's Manual, Polytechnic Institute of Brooklyn, 1971.

5. Sinden, F.,"Force, Mass, and Motion"(a film), Bell Telephone Laboratories, Murray Hill, New Jersey.

6. Knipling, E. F., "The Eradication of the Screw-Worm Fly", Scientific American, V. 203, no. 4, October, 1960.

7. Le Bricque, A. C., and J. C. Keller (editors), Advances in Insect Population Control by the Sterile-Male Technique, Technical Reports, series 44, International Atomic Energy Agency, Vienna, Austria, 1965.

Acknowledgement

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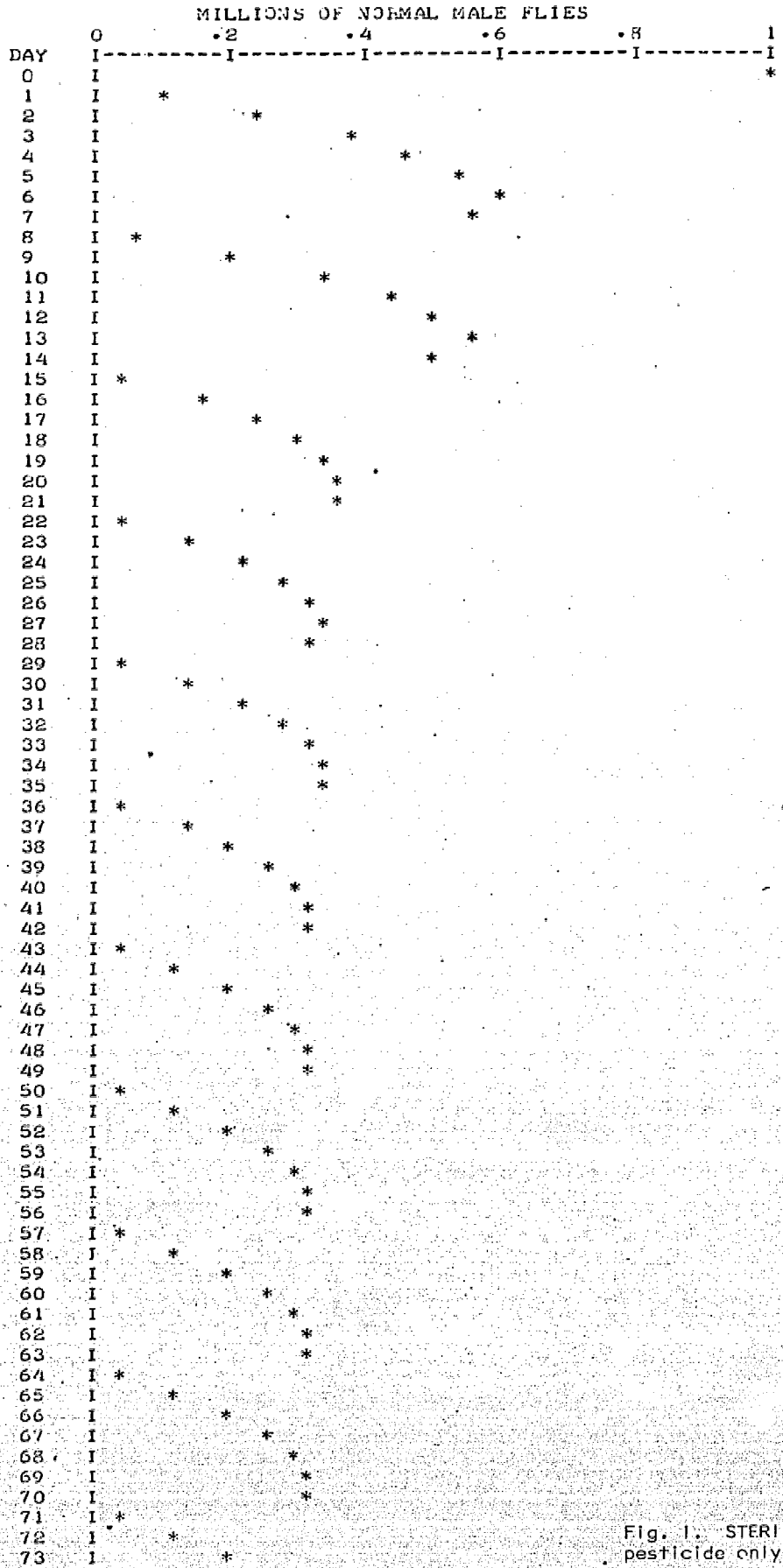

Fig. 1. STERIL run, with pesticide only, applied once every seven days.

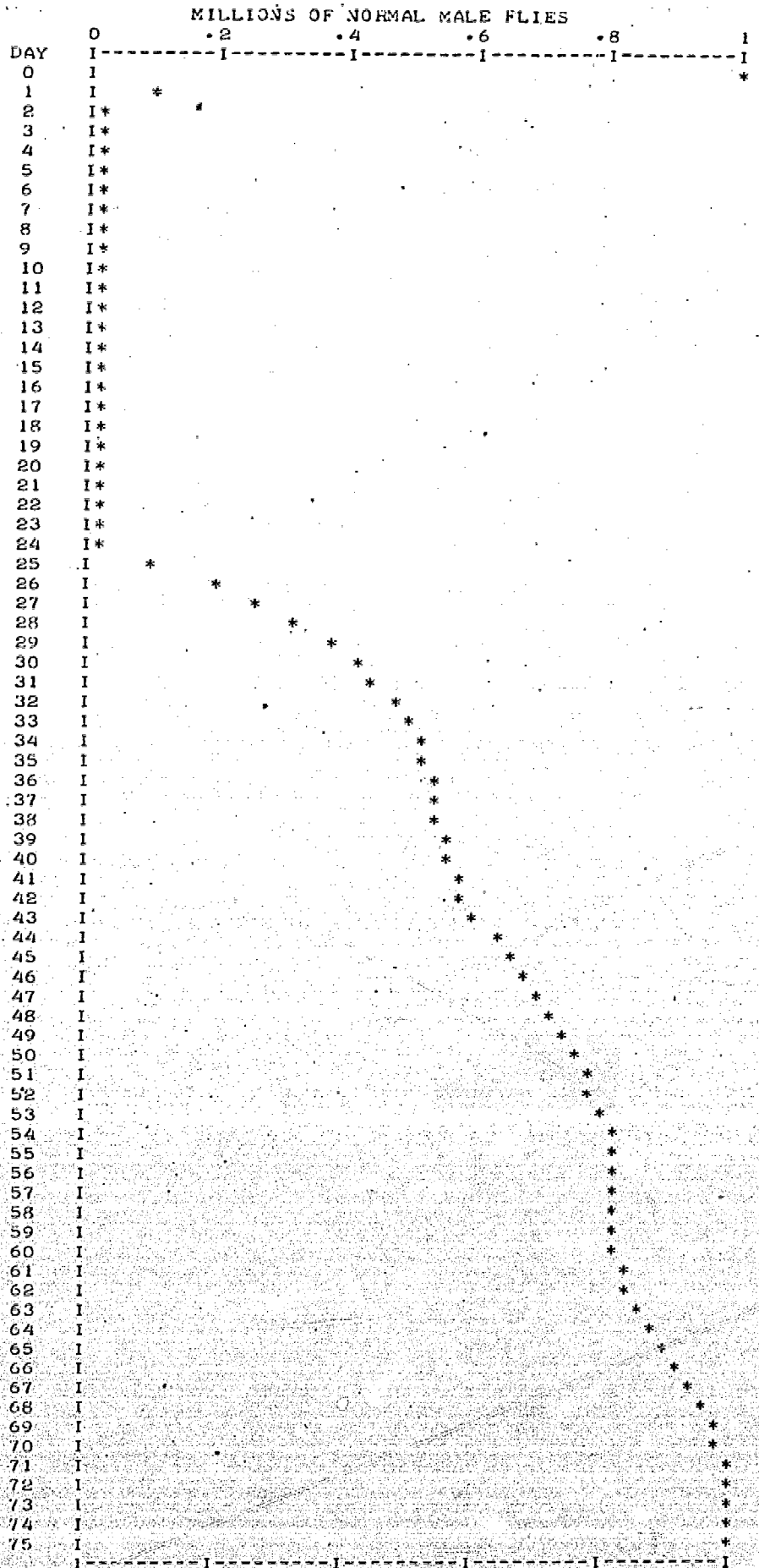

Fig. 2. STERIL run with pesticide only applied daily for first 24 days.

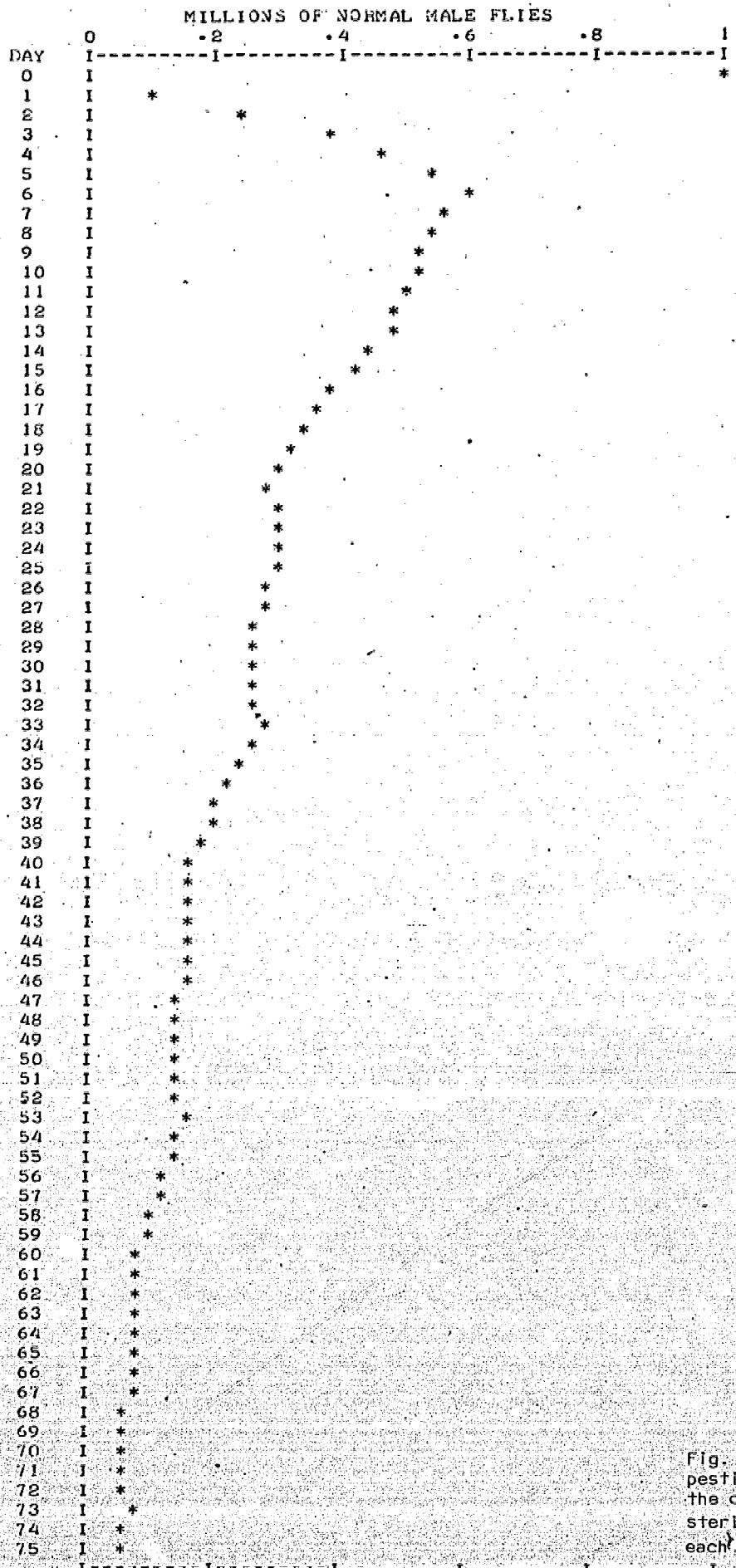

Fig. 3. STERIL run with pesticide applied only at the outset, and 100,000 sterile males released each day.

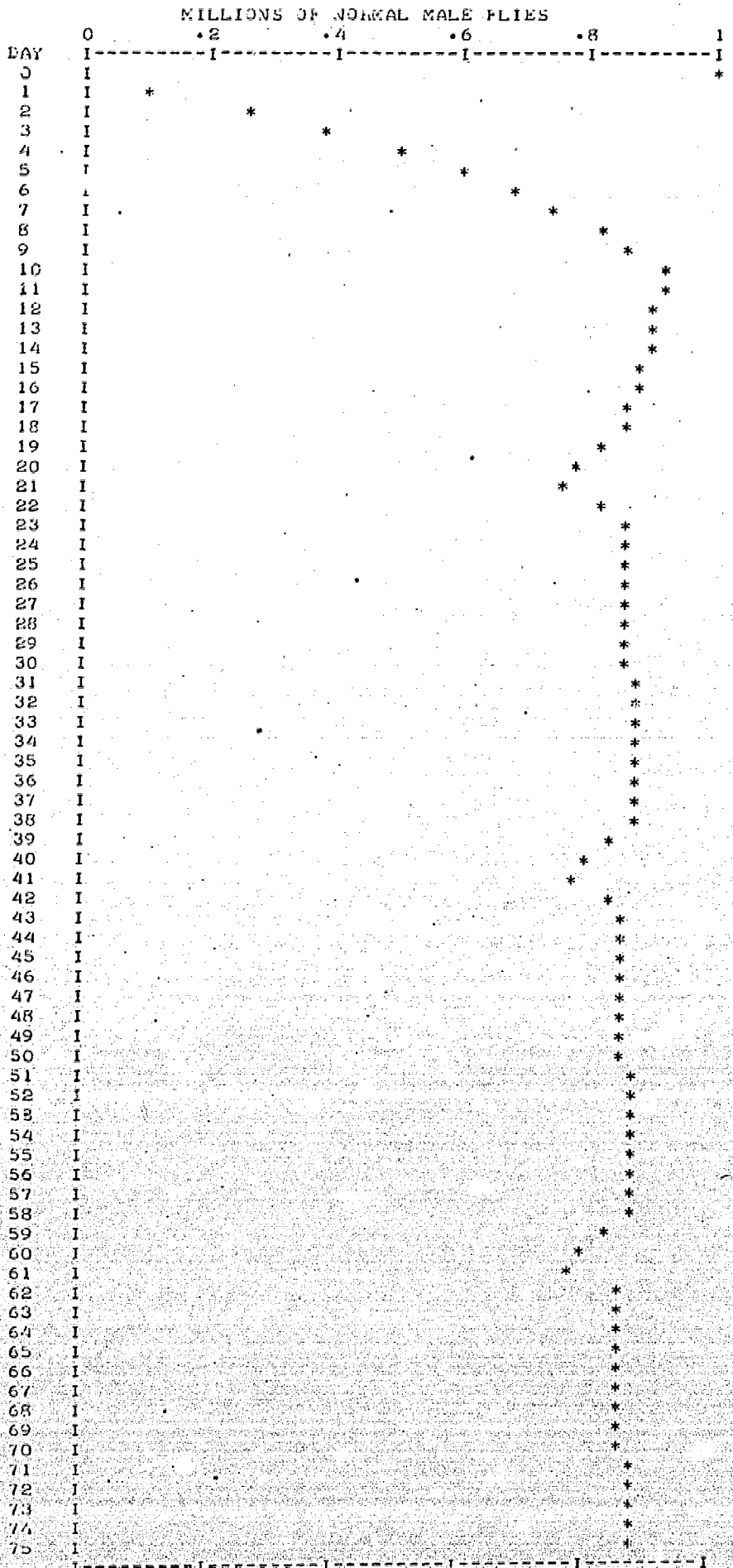

Fig. 4. STERIL run with pesticide applied only once, and 10,000 sterile males released each day.

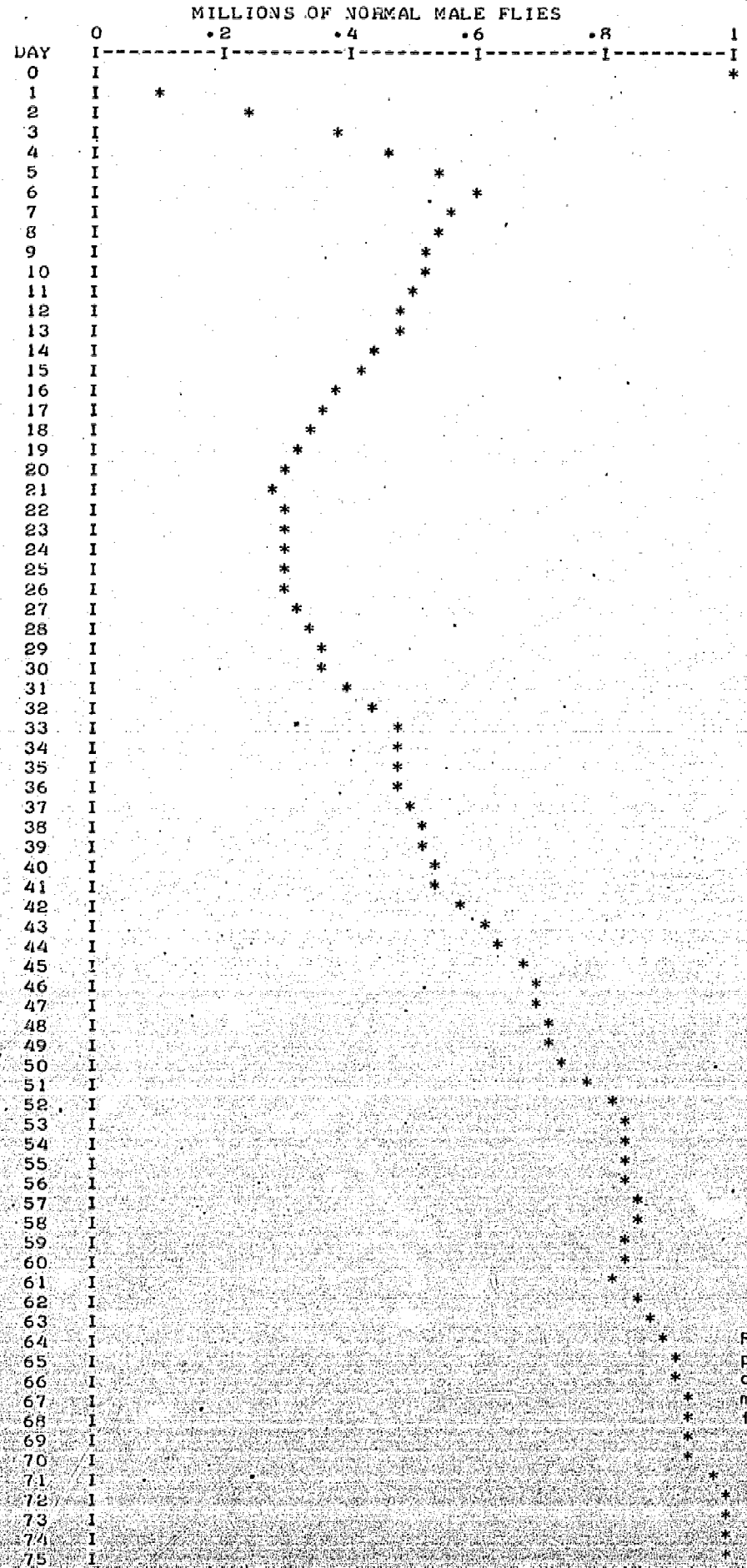

Fig. 5. STERIL run with pesticide applied only on day 1, and 100,000 sterile males released daily for first 24 days.

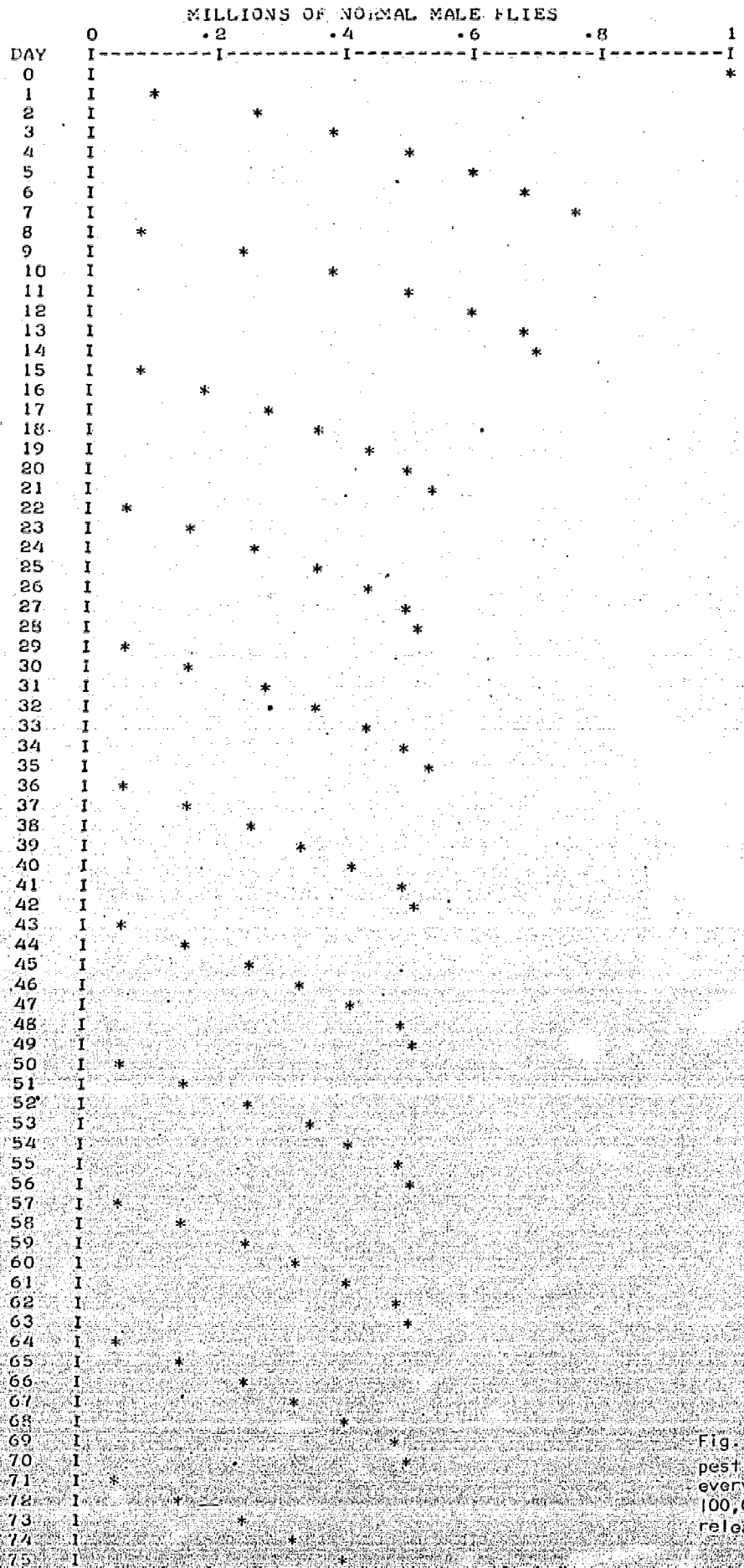

Fig. 6. STERIL run with pesticide applied once every seven days, and 100,000 sterile males released every day.

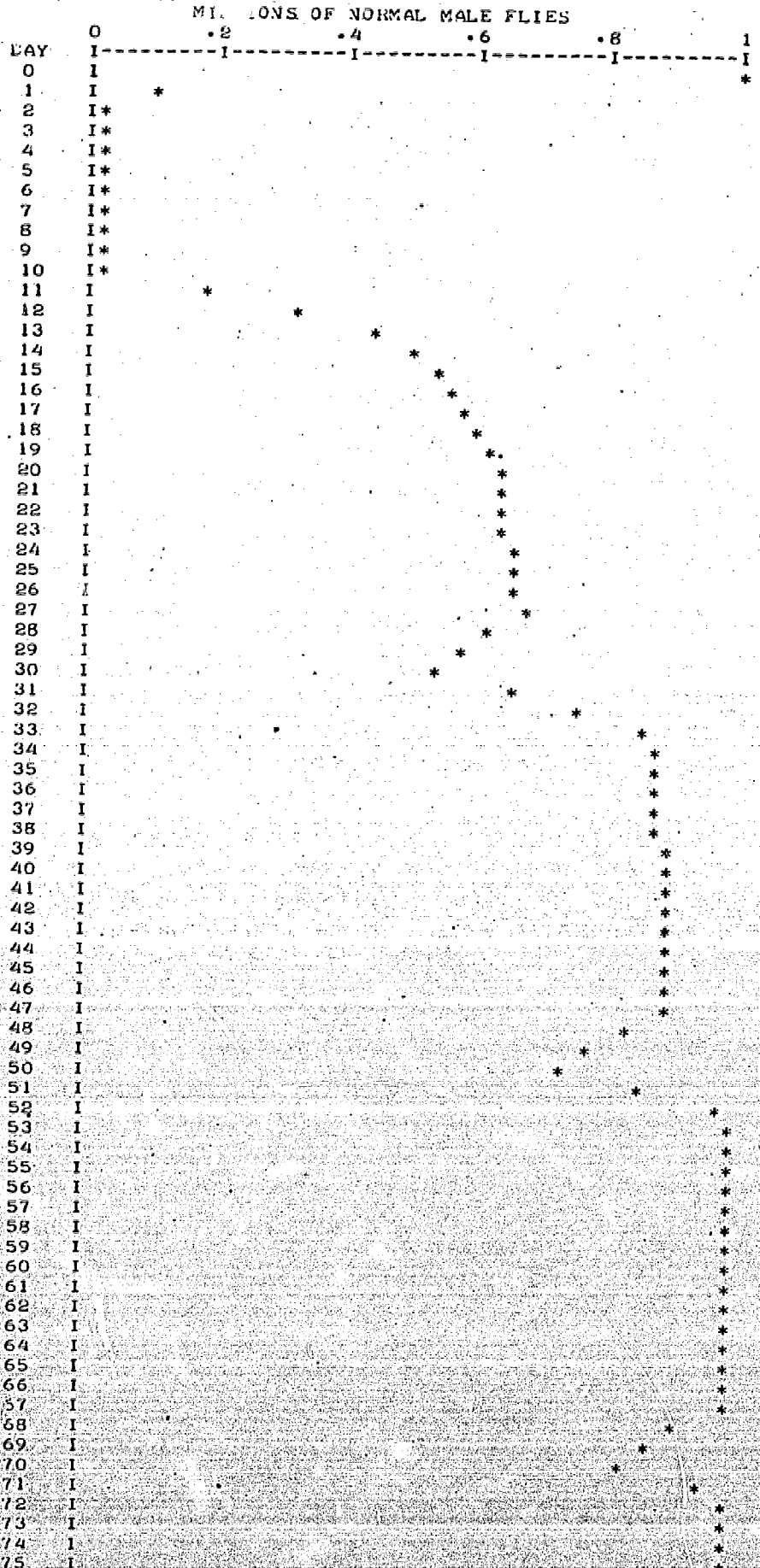

Fig. 7. STERIL run with pesticide applied daily for 10 days. No sterile males released.

```
LET F = THE FORWARD RATE CONSTANT
LETK= THE EQUILIBRIUM CONSTANT FOR THE REACTION A=P
TYPE IN THE CONSTANTS F AND K IN THAT ORDER
? 5,.5

                    ****************************

                    PERCENT CONCENTRATION OFA(*) AND P(+)

                0       25        50        75       100
                I---------I---------I---------I---------I
TIME
 0              +                                       *
 .046             +                                  *
 .092               +                             *
 .138                 +                         *
 .184                 +                         *
 .23                    +                     *
 .276                   +                     *
 .322                   +                     *
 .368                   +                     *
 .414                   +                     *
 .46                    +                     *
```

Fig. 8. KINET run with forward rate constant = 5; equilibrium constant = 0.1

```
LET F = THE FORWARD RATE CONSTANT
LETK= THE EQUILIBRIUM CONSTANT FOR THE REACTION A=P
TYPE IN THE CONSTANTS F AND K IN THAT ORDER
? 5,.2

                    ****************************

                    PERCENT CONCENTRATION OFA(*) AND P(+)

                0       25        50        75       100
                I---------I---------I---------I---------I
TIME
 0              +                                       *
 .023             +                                  *
 .046               +                             *
 .069                 +                         *
 .092                 +                         *
 .115                 +                         *
 .138                   +                     *
 .161                   +                     *
 .184                   +                     *
 .207                   +                     *
 .23                    +                     *
```

Fig. 9. KINET run with forward rate constant changed to 10. Same equilibrium as in Fig. 8. (Note change of time scale.)

```
 LET F = THE FOWARD RATE CONSTANT
 LET K = THE EQUILIBRIUM CONSTANT FOR THE REACTION A =P
 TYPE IN THE CONSTANTS F AND K IN THAT ORDER.
? 5 , 0.1

**********************************

                PERCENT CONCENTRATION OF A(*) AND P(+)

                0         25        50        75        100
 TIME           I---------I---------I---------I---------I
0               I+                                       *
.01254545       I  +                                    *
.02509091       I   +                                  *
.03763636       I   +                                  *
.05018182       I   +                                  *
.06272727       I    +                                *
.07527273       I    +                                *
.08781818       I    +                                *
.1003636        I    +                                *
.1129091        I    +                                *
.1254545        I    +                                *
```

Fig. 10. KINET run with same forward rate constant as in Fig. 8; equilibrium constant = 0.5

```
 LET F = THE FOWARD RATE CONSTANT
 LET K = THE EQUILIBRIUM CONSTANT FOR THE REACTION A =P
 TYPE IN THE CONSTANTS F AND K IN THAT ORDER.
? 10 , 0.1

**********************************

                PERCENT CONCENTRATION OF A(*) AND P(+)

                0         25        50        75        100
 TIME           I---------I---------I---------I---------I
0               I+                                       *
6.272727E-3     I  +                                    *
.01254545       I   +                                  *
.01881818       I   +                                  *
.02509091       I   +                                  *
.03136364       I    +                                *
.03763636       I    +                                *
.04390909       I    +                                *
.05018182       I    +                                *
.05645455       I    +                                *
.06272727       I    +                                *
```

Fig. 11. KINET run with same forward rate constant as in Fig. 8; equilibrium constant = 0.2

YOUNG'S DOUBLE SLIT EXPERIMENT

L = 2 METERS W = 6000 ANGSTROMS D = .5 MILLIMETERS

DISTANCE (MM'S FROM CENTER)

```
          -.26   .                        *
          -.24   .                         *
          -.22   .                        *
          -.2    .                  *
          -.18   .              *
          -.16   .     *
          -.14   .*
          -.12   *
          -.1    .*
          -.08   .     *
          -.06   .         *
          -.04   .              *
          -.02   .                   *
..............0....INTENSITY.....*
           .02   .                   *
           .04   .              *
           .06   .         *
           .08   .     *
           .1    .*
           .12   *
           .14   .*
           .16   .     *
           .18   .         *
           .2    .              *
           .22   .                   *
           .24   .                    *
           .26   .                   *
```

Fig. 12. Sample runs of SLITS. a. L = 2 m., W = 6,000 angstroms, D = 0.5 mm

```
WHAT IS THE NEW SLIT SEPARATION (D) IN MILLIMETERS? 0.2

L = 2 METERS     W = 6000 ANGSTROMS     D = .2 MILLIMETERS

DISTANCE (MM'S FROM CENTER)
          -.26    .*
          -.24    . *
          -.22    .  *
          -.2     .   *
          -.18    .    *
          -.16    .     *
          -.14    .      *
          -.12    .       *
          -.1     .        *
          -.08    .         *
          -.06    .          *
          -.04    .           *
          -.02    .            *
..............0....INTENSITY.....*
           .02    .            *
           .04    .           *
           .06    .          *
           .08    .         *
           .1     .        *
           .12    .       *
           .14    .      *
           .16    .     *
           .18    .    *
           .2     .   *
           .22    .  *
           .24    . *
           .26    .*
```

Fig. 12. continued. b. Same as Fig.12.a. except D = 0.2 mm

```
WOULD YOU LIKE TO TRY ANOTHER VALUE OF D (1-YES, 0-NO)? 1
WHAT IS THE NEW SLIT SEPARATION (D) IN MILLIMETERS? 1.0

L = 2 METERS     W = 6000 ANGSTROMS     D = 1 MILLIMETERS

DISTANCE (MM'S FROM CENTER)
          -.26   .                  *
          -.24   .                      *
          -.22   .                  *
          -.2    .     *
          -.18   *
          -.16   .     *
          -.14   .                  *
          -.12   .                      *
          -.1    .                  *
          -.08   .     *
          -.06   .
          -.04   .     *
          -.02   .                  *
..............0....INTENSITY......*
           .02   .                  *
           .04   .     *
           .06   *
           .08   .     *
           .1    .                  *
           .12   .                      *
           .14   .                  *
           .16   .     *
           .18   *
           .2    .     *
           .22   .                  *
           .24   .                      *
           .26   .                  *
```

Fig. 12. continued. c. Same as Fig. 12.a. except D = 1.0 mm

```
WHAT ARE THE TWO TRAITS TO BE STUDIED?
DOMINANT TRAIT? BROWN
RECESSIVE TRAIT? BLUE

******

GENOTYPE OF FEMALE PARENT? BROWN,BLUE

GENOTYPE OF MALE PARENT? BROWN,BLUE

HOW MANY OFFSPRING DO YOU WANT TO STUDY? 10

DETAILED REPORT(YES OR NO)? YES
```

OFFSPRING NO.	------GENOTYPE------		PHENOTYPE
	GENE 1	GENE 2	
1	BLUE	BROWN	BROWN
2	BLUE	BLUE	BLUE
3	BLUE	BROWN	BROWN
4	BROWN	BROWN	BROWN
5	BLUE	BLUE	BLUE
6	BLUE	BROWN	BROWN
7	BROWN	BLUE	BROWN
8	BLUE	BLUE	BLUE
9	BROWN	BLUE	BROWN
10	BLUE	BROWN	BROWN

```
**********
GENOTYPE RATIO      1 : 6 : 3
PHENOTYPE RATIO     2.333333 : 1
```

Fig. 13. Sample run of GENE1 with 10 offspring.

```
GENOTYPE OF FEMALE PARENT? BROWN,BLUE

GENOTYPE OF MALE PARENT? BROWN,BLUE

HOW MANY OFFSPRING DO YOU WANT TO STUDY? 100

DETAILED REPORT(YES OR NO)? NO

**********
GENOTYPE RATIO      1 : 1.586207 : .662069
PHENOTYPE RATIO     3 : 1

##########
```

Fig. 14. GENE1 output with 100 offspring.

```
******

GENOTYPE OF FEMALE PARENT? BROWN,BLUE

GENOTYPE OF MALE PARENT? BROWN,BLUE

HOW MANY OFFSPRING DO YOU WANT TO STUDY? 1000

RATIOS ONLY WILL BE TYPED, BECAUSE OF
LARGE NO. OF OFFSPRING.

**********
GENOTYPE RATIO      1 : 2.116667 : 1.05
PHENOTYPE RATIO     2.966254 : 1

##########
```

Fig. 15. GENE1 with 1,000 offspring.

```
******

GENOTYPE OF FEMALE PARENT? BROWN,BLUE

GENOTYPE OF MALE PARENT? BROWN,BLUE

HOW MANY OFFSPRING DO YOU WANT TO STUDY? 10000

RATIOS ONLY WILL BE TYPED, BECAUSE OF
LARGE NO. OF OFFSPRING.

**********
GENOTYPE RATIO      1 : 1.932224 : 1.031312
PHENOTYPE RATIO     2.643196 : 1

##########
```

Fig. 16. GENE1 with 10,000 offspring.

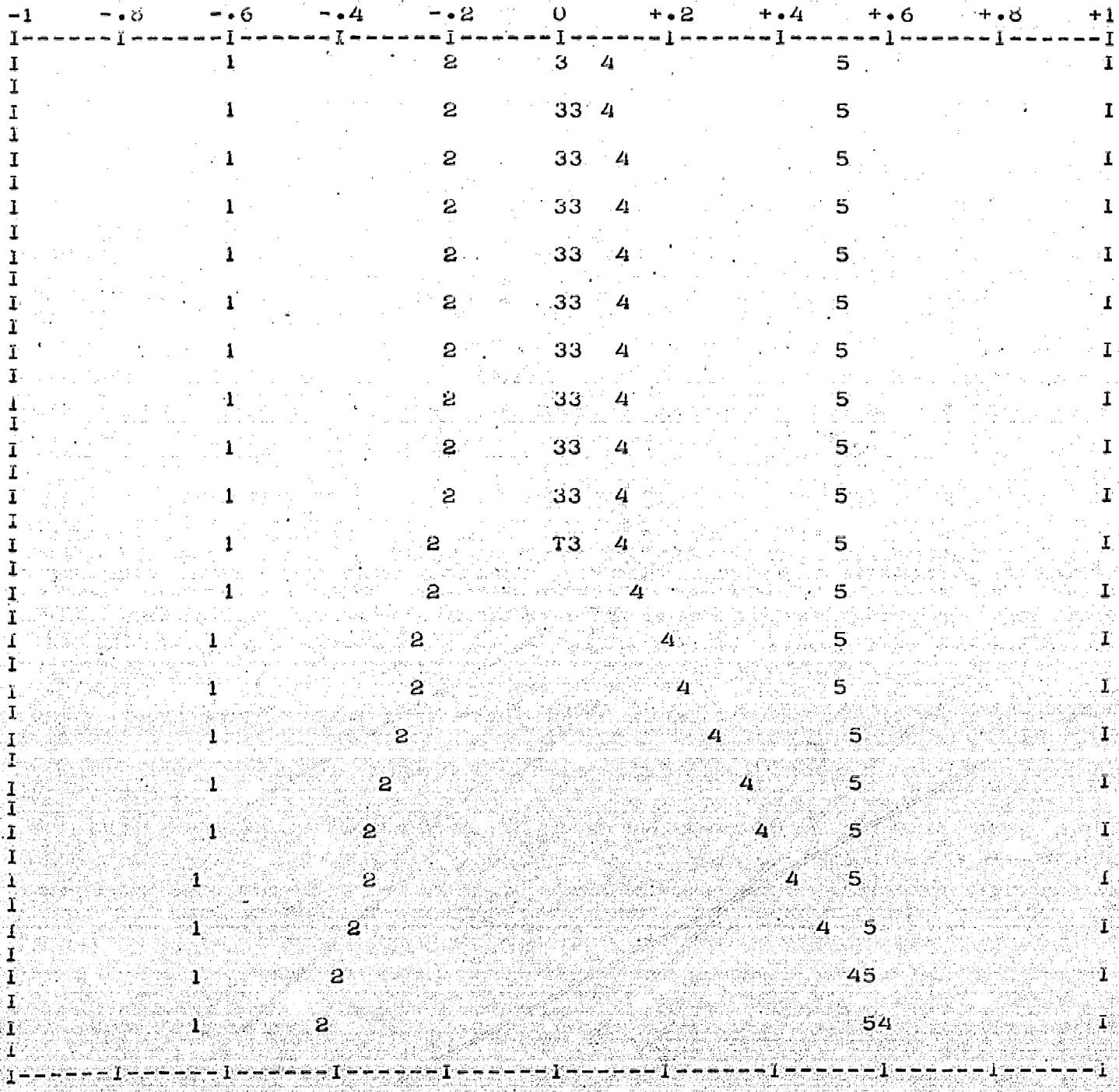

Fig. 17. Sample run of SCATTER.

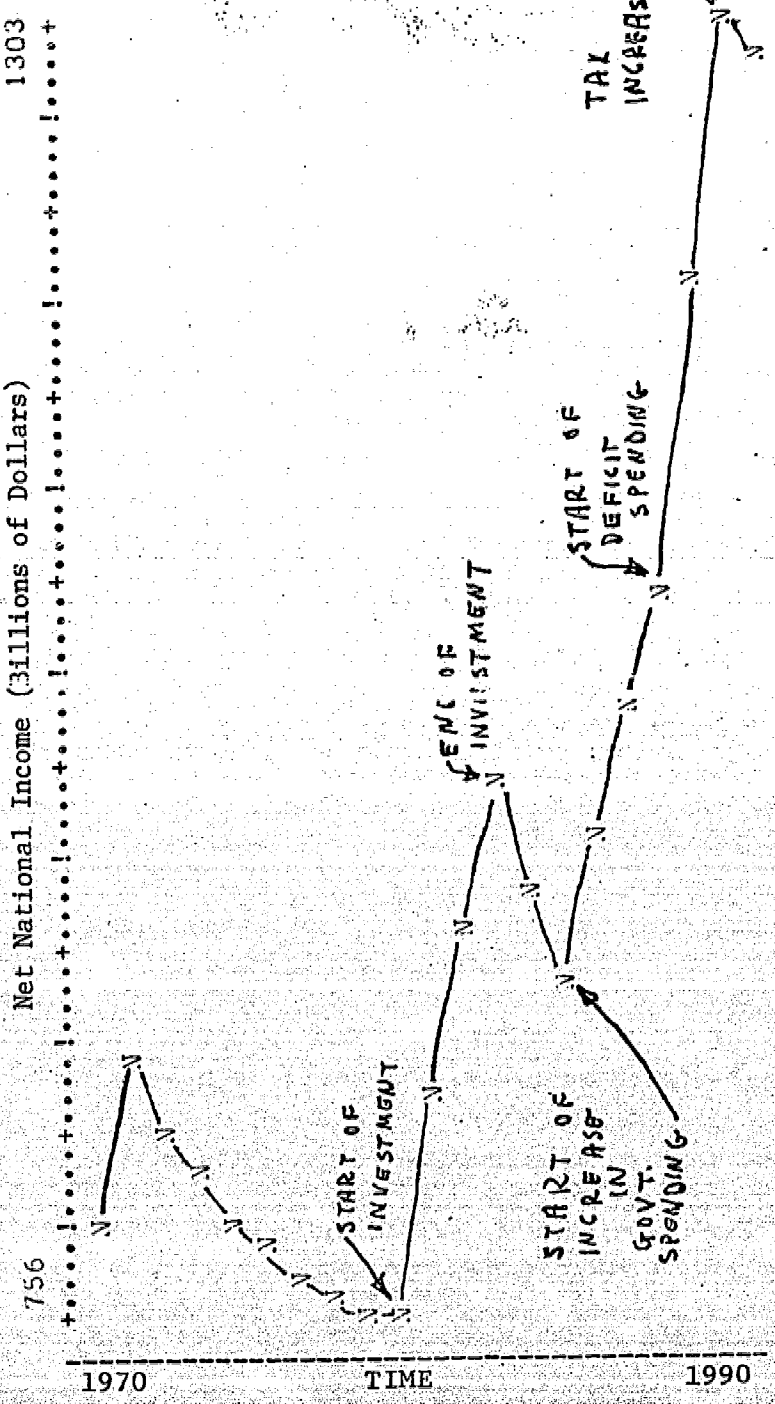

Fig. 18. Sample run of ECON1 with various changes in investment, tax, and spending policies.